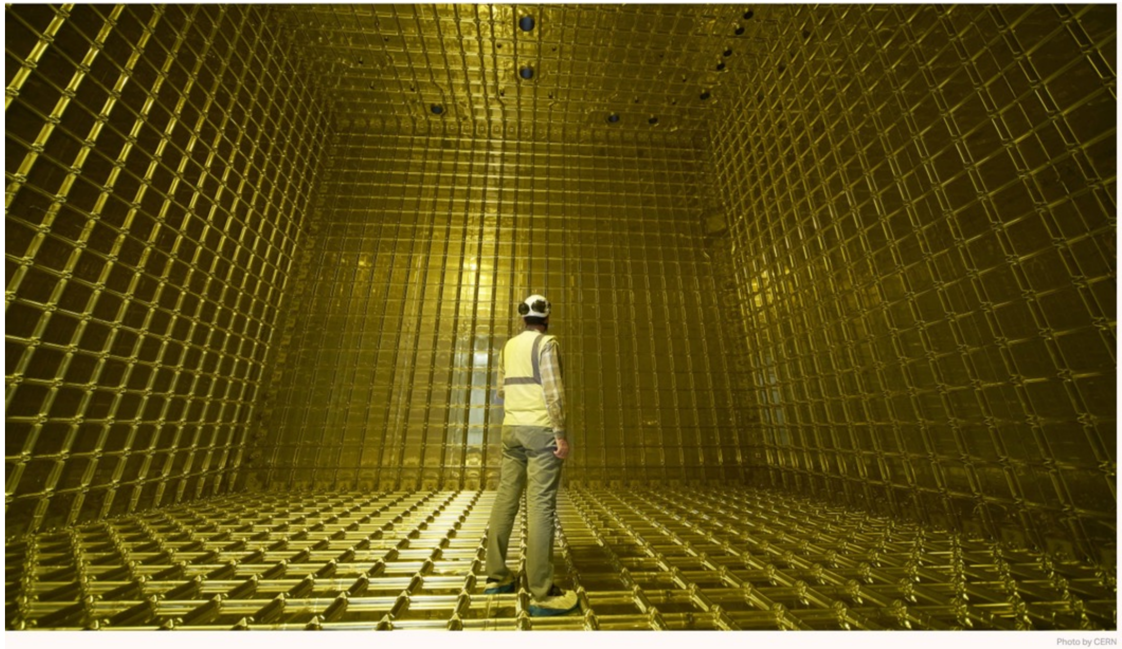
DUNE Far and Near Detectors



ProtoDUNE-SP
a far detector prototype

Sam Zeller
Fermilab
P5 Town Hall
March 21, 2023

2x2 Demonstrator
a near detector prototype

Unique Features of DUNE

(1) 1300 km baseline

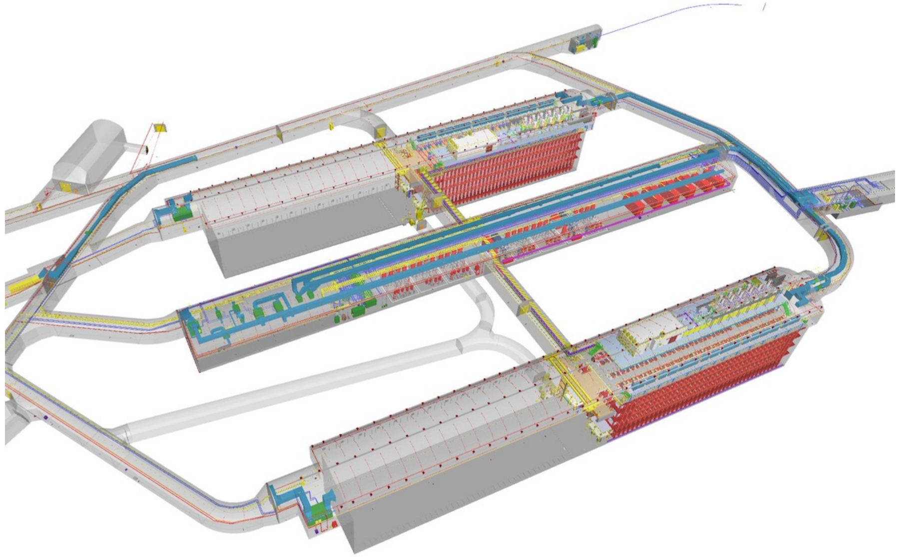
- *unambiguously measure mass ordering and CPV*
- *do not have to look for inputs from other places*

(2) wide band beam

- *with baseline means optimal ν oscillation physics*
- *increased BSM sensitivity*

this talk
(with a focus on
Phase I)

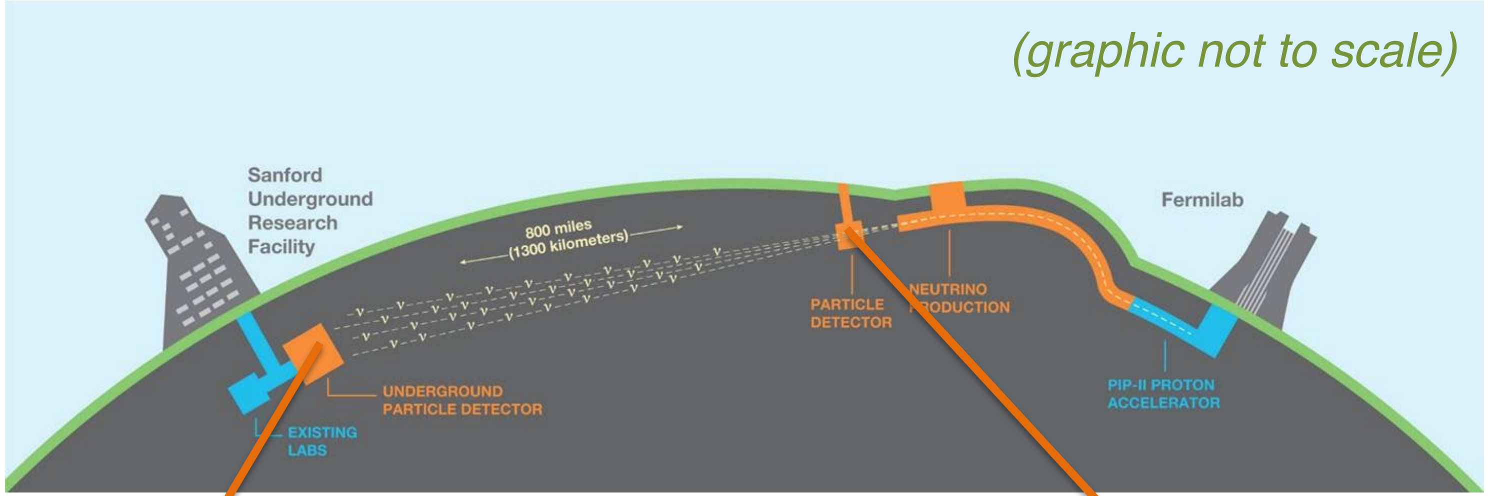
(3) liquid argon technology



- *much higher resolution, higher efficiency ν detection*
- *enables wide band physics*

Near and Far Detectors in a Nutshell

LAr TPCs at both the near and far sites



Far Site

- *1300km from the proton source*
- *very large LAr TPCs (each 17 ktons)*
- *underground in South Dakota*

Near Site

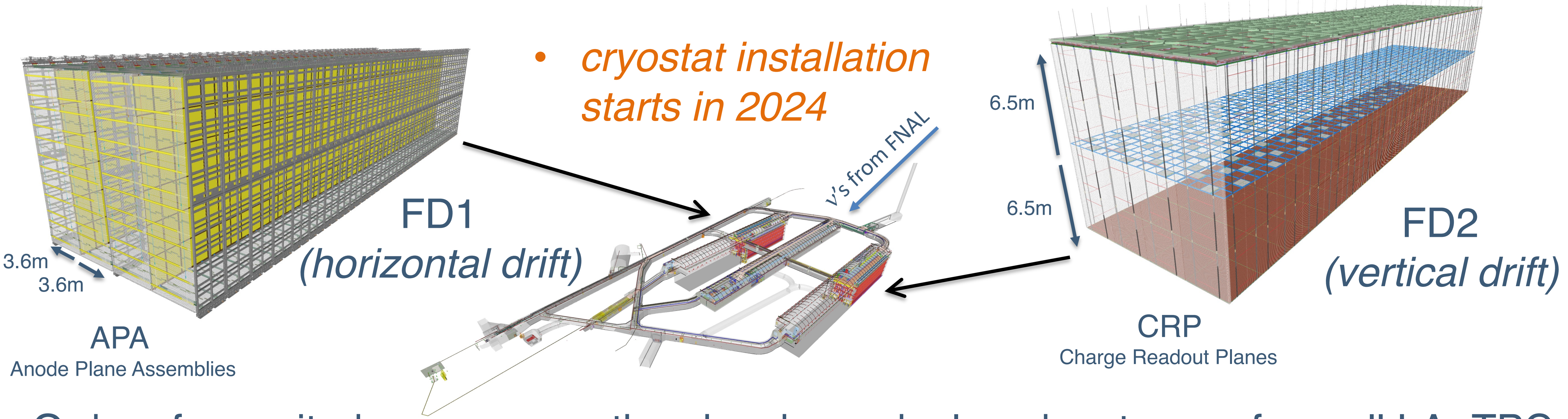
- *550m from proton source*
- *on-site at Fermilab*
- *both stationary & moveable detectors*

- Use of the LAr TPC technology enables wide band beam physics. A lot more info available. Means better ν oscillation physics and increased BSM sensitivity. There is no other experiment in the world like this. This is what sets DUNE apart.

DUNE Far Detectors (Phase I)

(Chris Mossey's talk)

- Phase 1 will include caverns for 4 detector modules in South Dakota and 2 far detector modules, each 17 kton of LAr, the largest LAr TPCs ever constructed.
  - *FD1: horizontal drift (ala ICARUS, MicroBooNE)*
  - *FD2: vertical drift (capitalizing on protoDUNEs)*



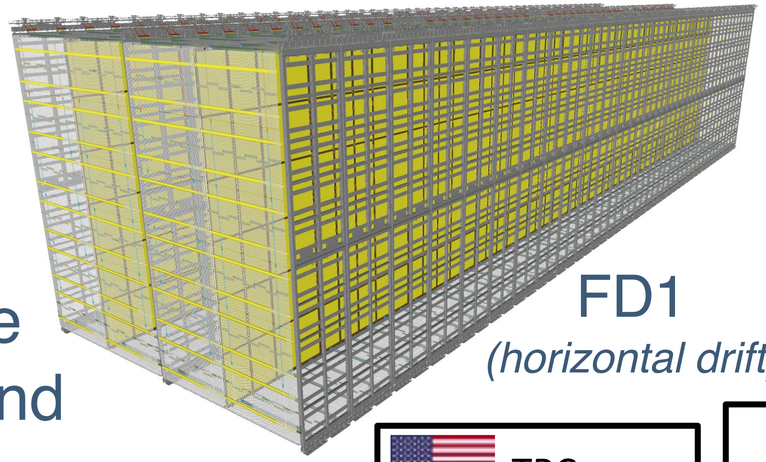
- Order of magnitude more mass than has been deployed up to now from all LAr TPCs

Far Detector Partners (Phase I)

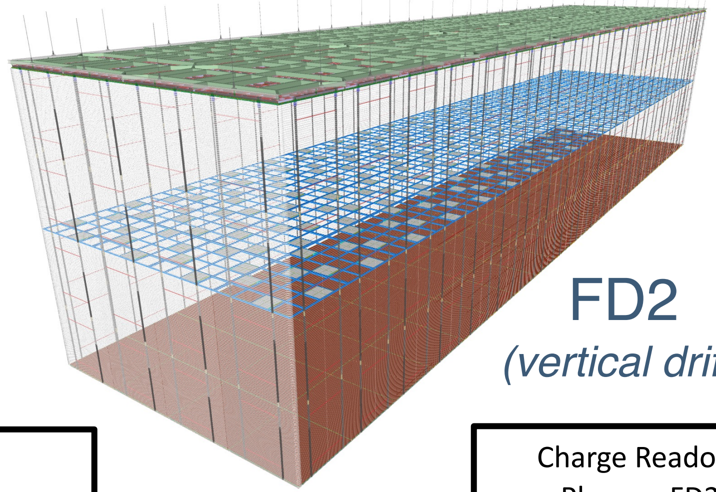
(Mary Bishai's talk)

- Multiple international partners have invested significant resources in the DUNE FDs

- ~50/50 share U.S./non-U.S (M&S)
- our partners are preparing to send detectors and components
- we are on schedule and getting ready to build these detectors!



FD1
(horizontal drift)



FD2
(vertical drift)

High Voltage FD1, FD2

Anode Plane Assemblies - FD1

TPC Electronics FD1, FD2-B

Photon Detection FD1, FD2

Data Acquisition FD1, FD2

Charge Readout Planes - FD2

CALCI FD1, FD2

Electronics FD2-T

Brookhaven National Laboratory

BERKELEY LAB

Argonne NATIONAL LABORATORY

Fermilab

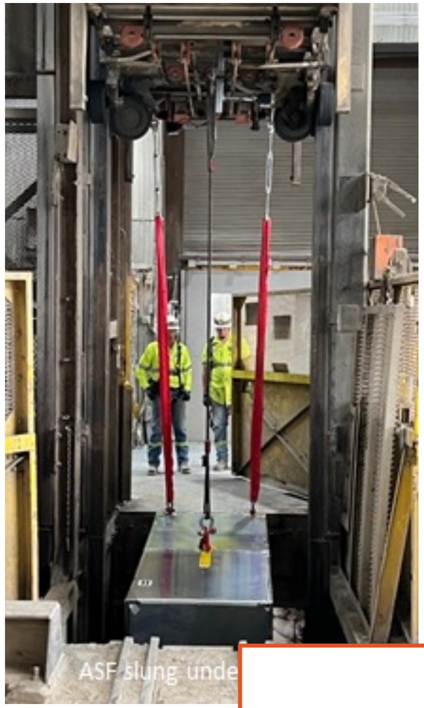
Los Alamos NATIONAL LABORATORY

+ many Universities

As One Example

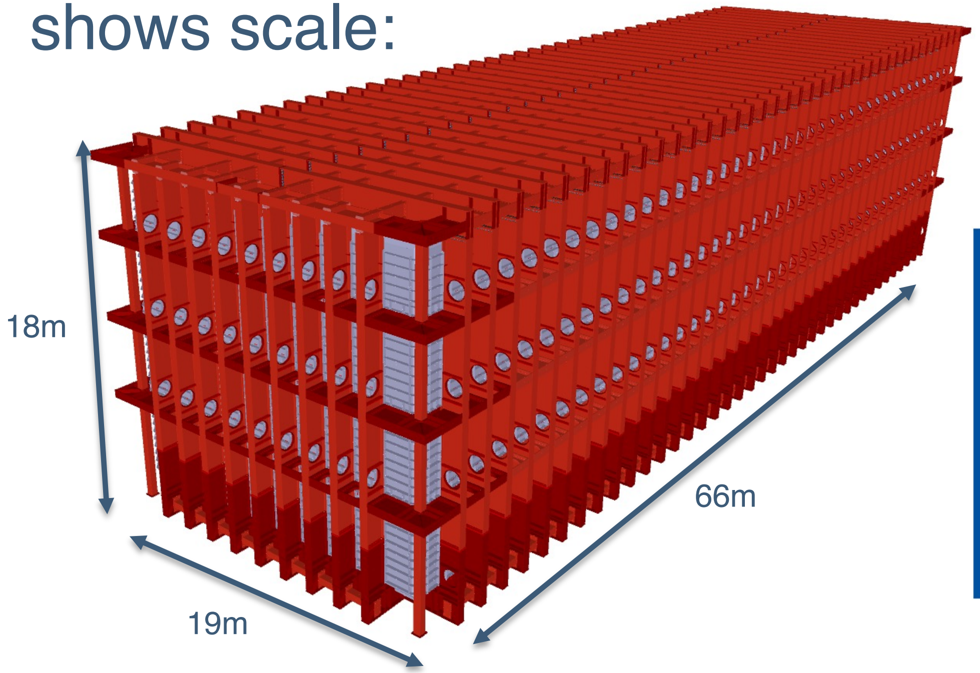
- In November, FD1 Anode Plane Assembly (APA) test lift was successfully completed at SURF demonstrating that largest detector components can be successfully moved to 4850L
  - *Recent Symmetry Magazine article, "How to Put Together an International Physics Experiment", M. O'Keefe, March 14, 2023*

APAs being tested at Daresbury Laboratory, UK; one ~2m x ~6m APA is shown

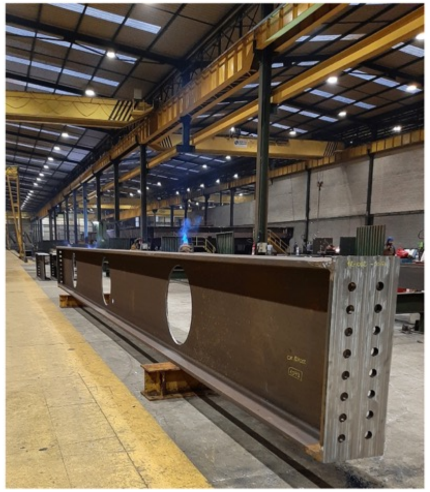


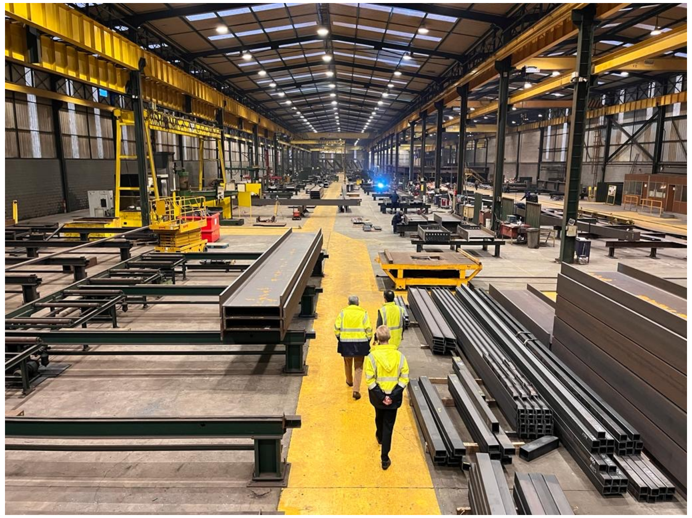
Cryostats for the Far Detectors (Phase I)

shows scale:



- fabrication of the 1st cryostat is underway →





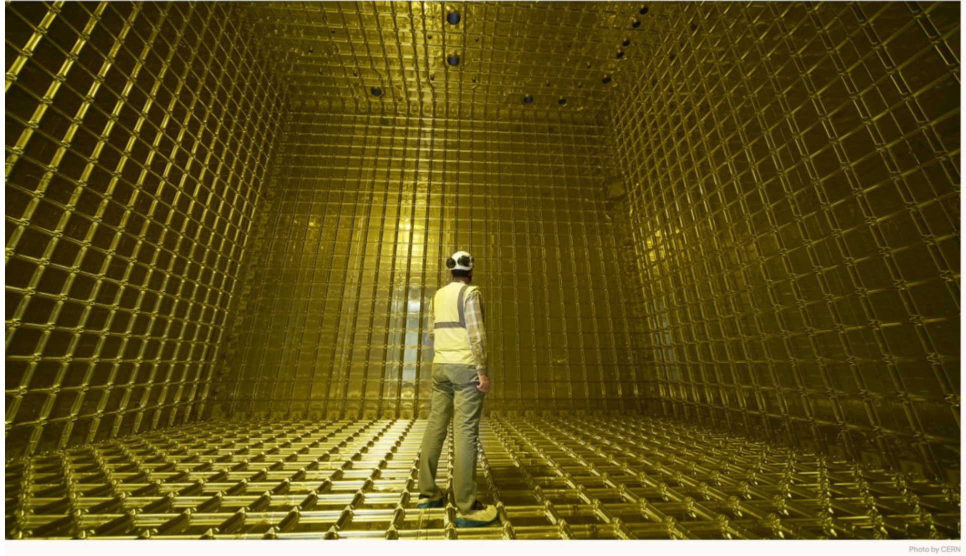
CERN also contributing to:

- *high voltage (both FD1, FD2)*
- *DAQ (both FD1, FD2)*
- *APAs (cold testing, shipping frames)*
- *CRPs (anode PCBs procurement, assembly)*
- *cryogenics (argon receiving tanks)*

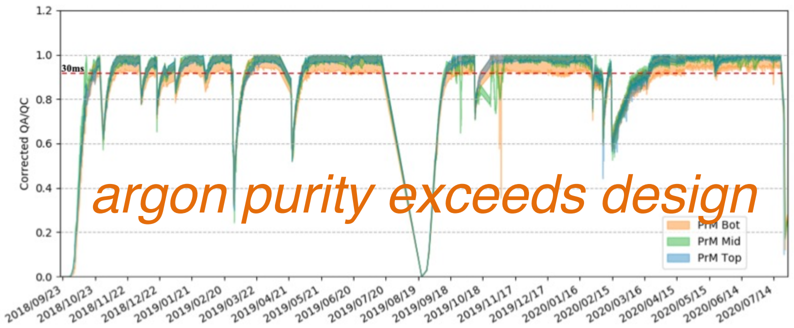
this is the 1st time CERN is contributing to an infrastructure project outside of Europe

Prototypes of the Far Detector

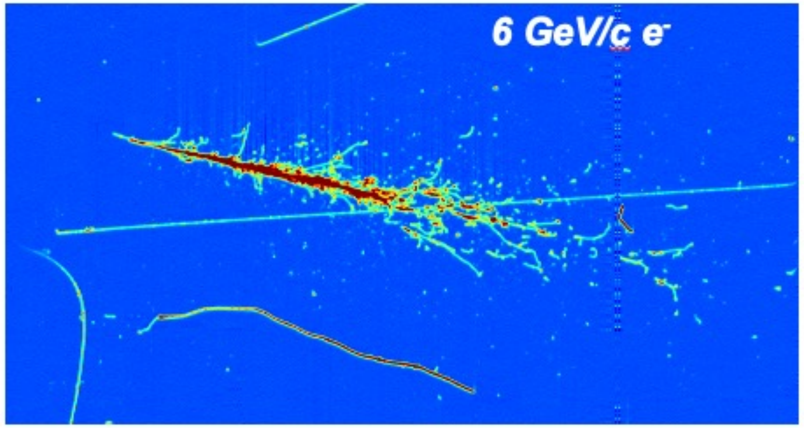
- Very successful operation of prototypes of the FDs at the Neutrino Platform at CERN → protoDUNEs
- Getting physics out of these prototypes through their exposure to the CERN testbeam
- ProtoDUNEs have established the technology at scale, plus are also providing important e,π,K re-scattering data on argon

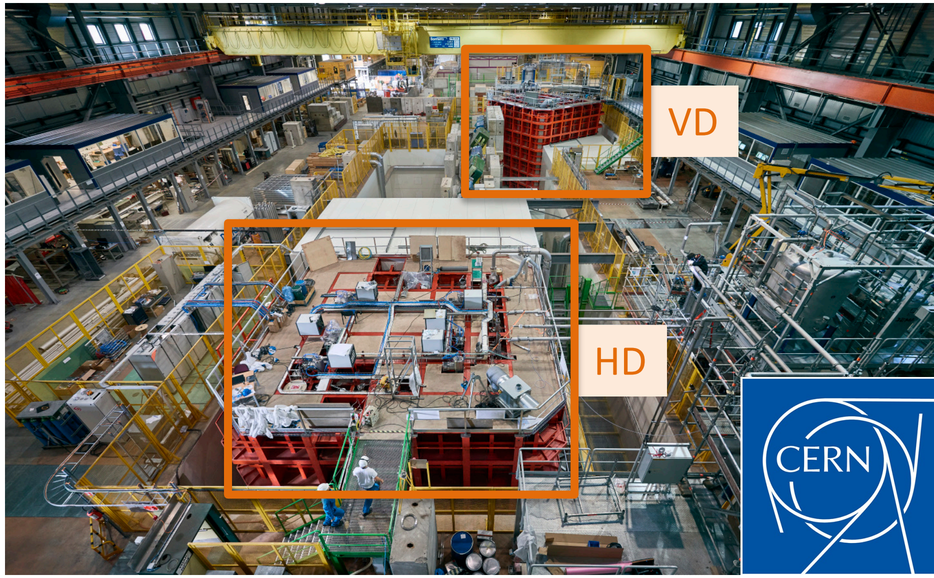


(Francesco Lanni's talk)



JINST 17, PO1005 (2022)





CERN Neutrino Platform

Prototypes of the Far Detector

- Very successful operation of prototypes of the FDs at the Neutrino Platform at CERN → protoDUNEs
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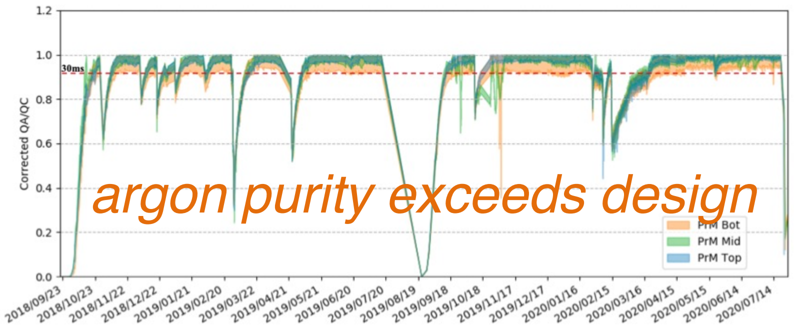
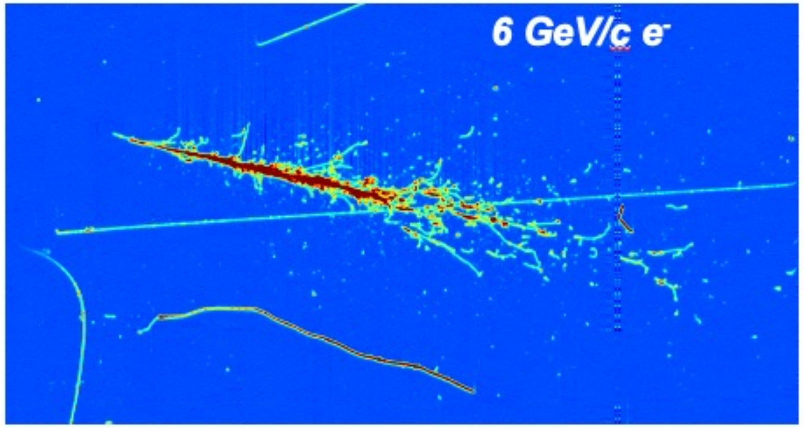


JINST 17, PO1005 (2022)



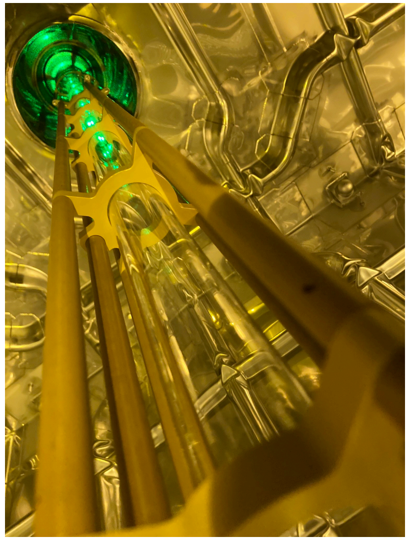
- *Identification of Low Energy Electrons in the ProtoDUNE-SP Detector, arXiv:2211.0166, submitted for publication*
- *Reconstruction of Interactions in the ProtoDUNE-SP Liquid Argon TPC Detector with Pandora, arXiv: 2206.14521, submitted for publication*
- *Separation of Track and Shower-like Energy Deposits in ProtoDUNE-SP Using a CNN, Eur. Phys. J. C82, 903 (2022)*
- *Scintillation Light Detection in the 6m Drift ProtoDUNE-DP Detector, Eur. Phys. J. C82, 618 (2022)*
- *Xenon Doping of Liquid Argon in ProtoDUNE-SP, JINST 17, C01034 (2022)*
- *Design, Construction, and Operation of the ProtoDUNE-SP Liquid Argon TPC, JINST 17, P01005 (2022)*
- *First Results on ProtoDUNE-SP Performance from a Beam Test at the CERN Neutrino Platform, JINST 15, P12004 (2020)*
- *First Calorimetric Energy Reconstruction of Beam Events with ARAPUCA Light Detectors in ProtoDUNE-SP, JINST 15, C03033 (2020)*

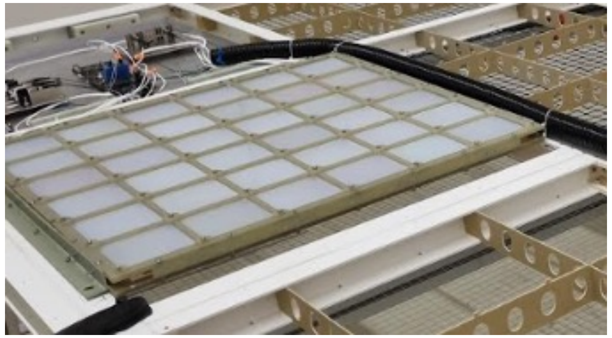
We have come a long way with LAr TPCs

- There have been major technological advances over many years. An explosion of innovation.
  - charge readout *(CRPs, pixels)*
  - light collection *(X-ARAPUCA, power over fiber)*
  - Xe doping
  - cryogenic *(in-liquid)* front-end electronics
  - membrane cryostats
  - argon purification *(without evacuation)*
  - achievement of long drift distances *(meters)*
  - sophisticated event reconstruction *(AI/ML)*
- This evolution is informing Phase II *(Mary Bishai)*
- Plus, a lot of high-caliber data and physics …

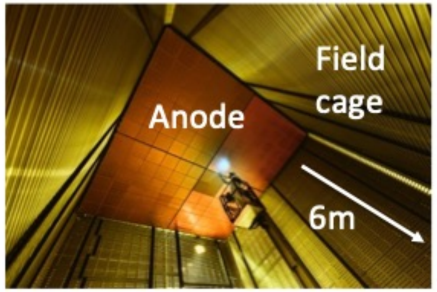
these are not your grandmother's LAr TPCs

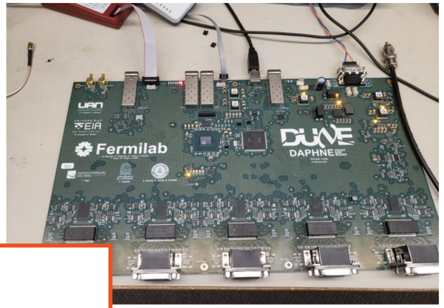
Brookhaven National Laboratory





detector R&D is important



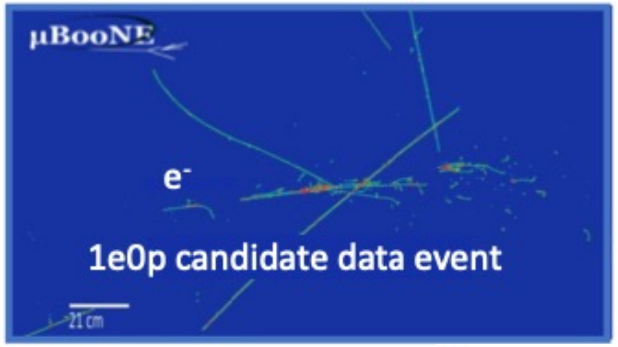


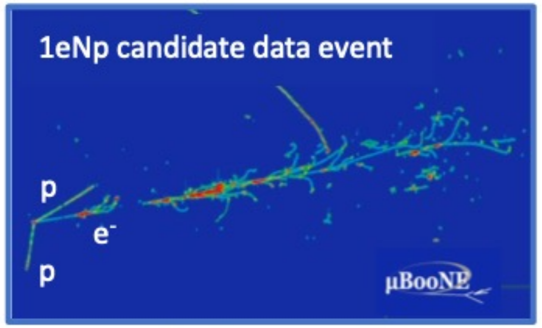
Fermilab DUNE

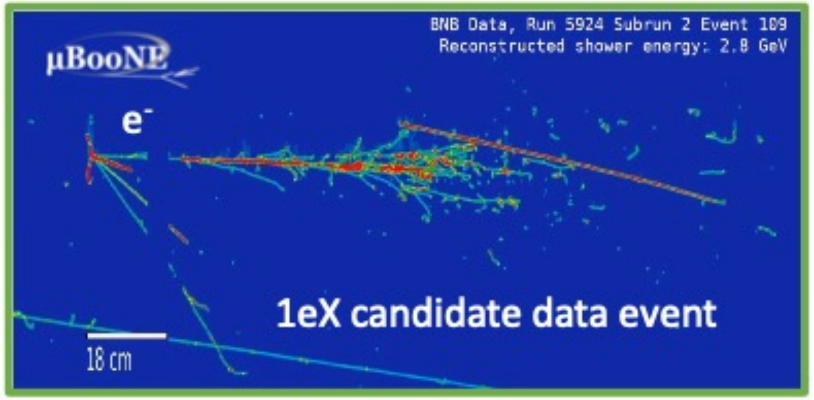
Liquid Argon Detectors Work And They Work Extremely Well

- In a short amount of time, combination of results from ProtoDUNEs, MicroBooNE, ICARUS, ArgoNeuT have clearly demonstrated that LAr TPCs have lived up to their promise. They are a game changer.
- A recent example is MicroBooNE
  - *DUNE-like ν_e analysis included 3 different event recos, 4 final states →*
  - *results went far beyond what was originally planned*
  - *52 publications, 82 public notes*
- More to come from SBN!
  - *1st time with a near & far LAr TPCs in the same ν beam*

(Ornella Palamara's talk)







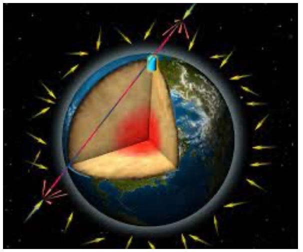
Are these detectors all they are cracked up to be? Yes!

- new since the last P5

Non-Beam Physics with the Far Detectors (Phase I)

- DUNE science begins as soon as far detectors turn on (2028). *(Chris Marshall's talk)*
- DUNE will collect large samples of ν's from the earth's atmosphere, sun, and from a Galactic core-collapse supernovae. Plus will look for BSM physics & nucleon decay. Information coming from DUNE is very different. Important comparisons with JUNO, Hyper-K possible. Gets even better with Phase II!

Atmospheric neutrinos

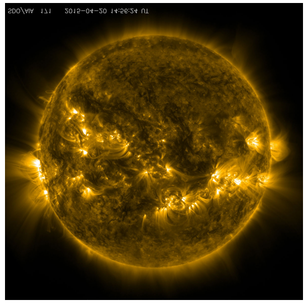


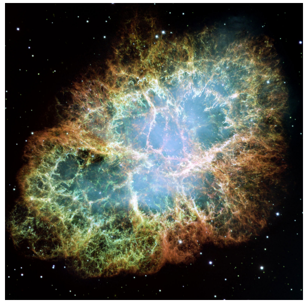
- *While not as sensitive, are also a tool for studying ν oscillations to compare with beam ν's*
- *Important theory work showing new types of analyses possible because of LAr TPC in DUNE*

C. Ternes, S. Gariazzo, R. Hajjar, O. Mena, M. Sorel, M. Tortola, PRD 100, 093004 (2019)

K. Kelly, P. Machado, I. Martinez-Soler, S. Parke, Y. Perez-Gonzalez, PRL 123, 081801 (2019)

K. Kelly, P. Machado, I. Martinez-Soler, Y. Perez-Gonzalez, JHEP 05, 187 (2022)





Solar neutrinos

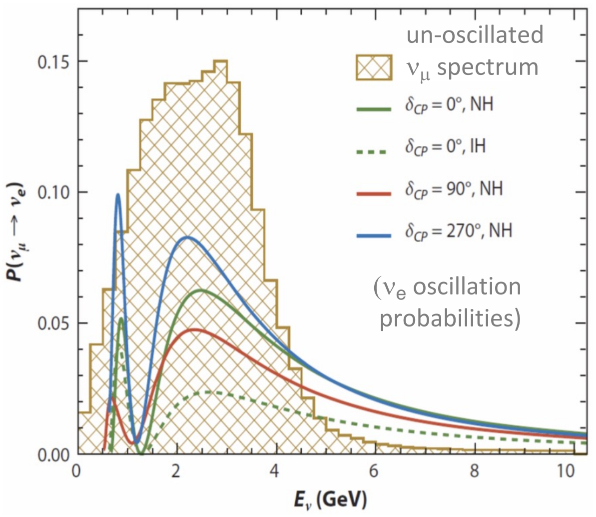
- *will measure ^8B and the yet un-observed hep solar ν flux in Phase 1*
- *With ability to measure solar ν's, will be able to measure all of the ν mixing parameters in a single experiment*

Supernova neutrinos

- *unique sensitivity to ν_e due to LAr*
- *will immediately be a part of SNEWS*

Beam Physics with the Far Detectors

- DUNE is unique in that we can unambiguously distinguish the MO, CPV and do not require inputs from other experiments.



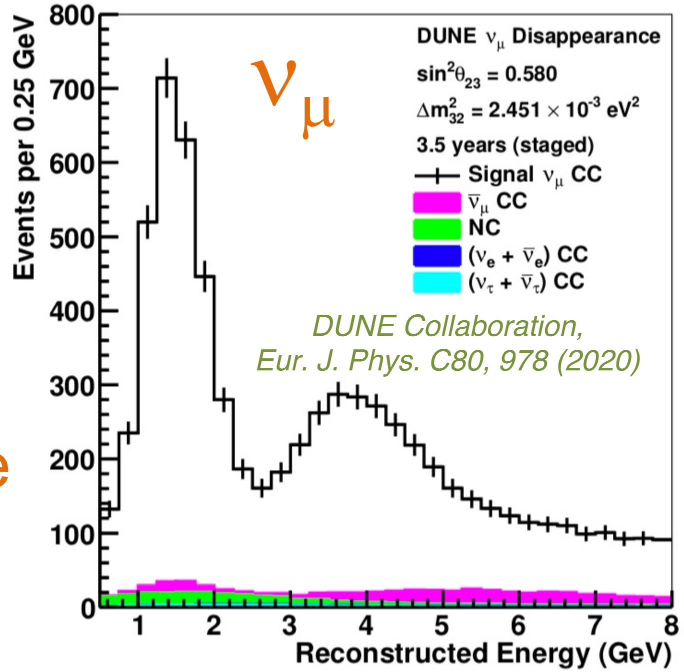
- Phase II is critical!

(Chris Marshall's talk)

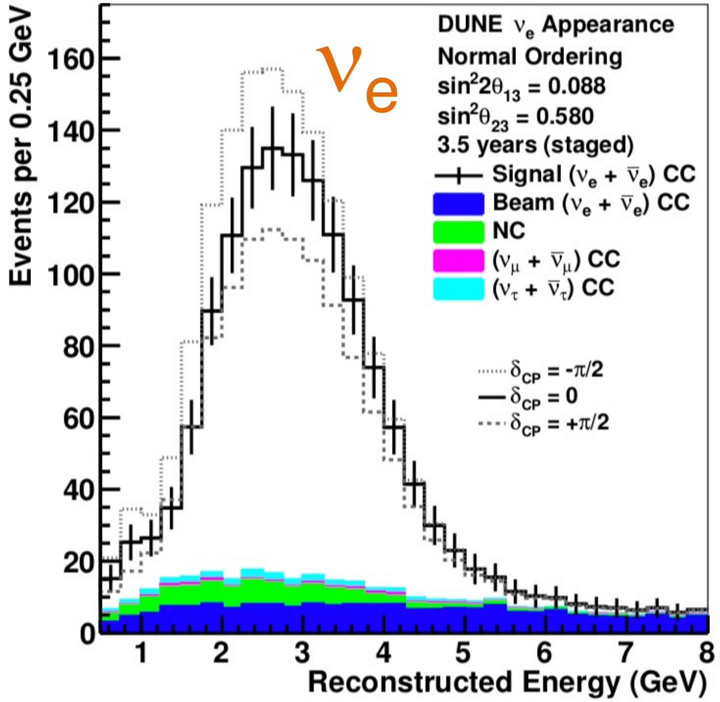
disappearance

$\nu_\mu \to \nu_e$

appearance



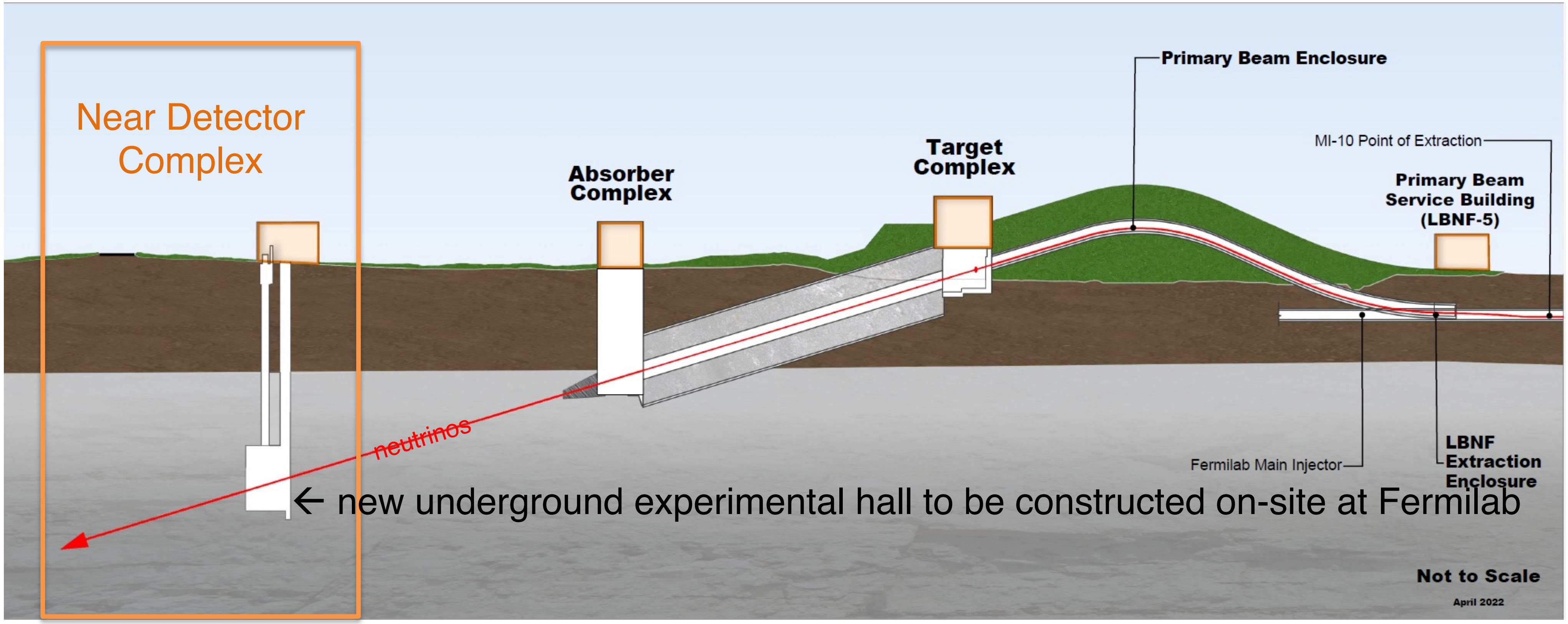
DUNE Collaboration, Eur. J. Phys. C80, 978 (2020)



- When beam turns on, the DUNE far detectors will collect ~150 oscillated ν_e events in the first year alone. This is larger than each of the current NOvA, T2K ν_e data sets. We immediately hit the ground running.

  - assuming a beam ramp-up to 1.2 MW, 2 FDs, normal ordering, δ_{CP}=0
  - expected range is 70-180 ν_e events in FHC, depends on true MO, CP

Near Detector Complex

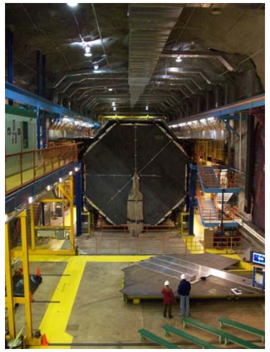


- **Where?** ND hall is 550 m from proton target, 215 ft deep, on-site at Fermilab.
- **Why?** Purpose of the ND is to measure the rate & spectrum of ν's before they have had a chance to oscillate. ND measures how the ν's will appear in the FD.

DUNE Near Detector (Phase I)

- DUNE ND is optimized with same technology as FD
- Design follows a long history of highly successful long-baseline ν experiments
  - **near detector matches the far detector**
  - *examples: MINOS and NOvA*
- For DUNE, this means having a LAr tracking calorimeter at the near site that is capable of handling the LBNF rate
  - *$\gtrsim$ 50 ν interactions in a single beam spill*
  - *unique environment requires innovation*
  - *LAr-based ND for DUNE is designed with pixelated readout and optical segmentation*
- **near detector measurements both on & off axis**

MINOS near detector

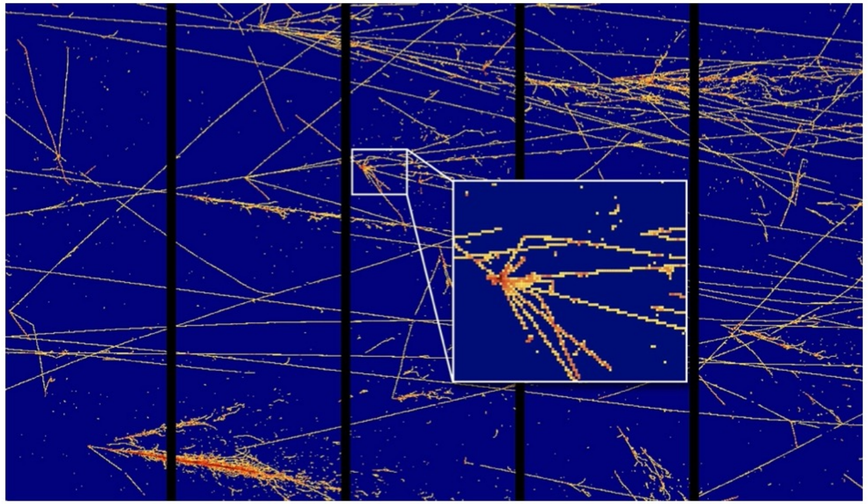


MINOS far detector

NOvA near detector

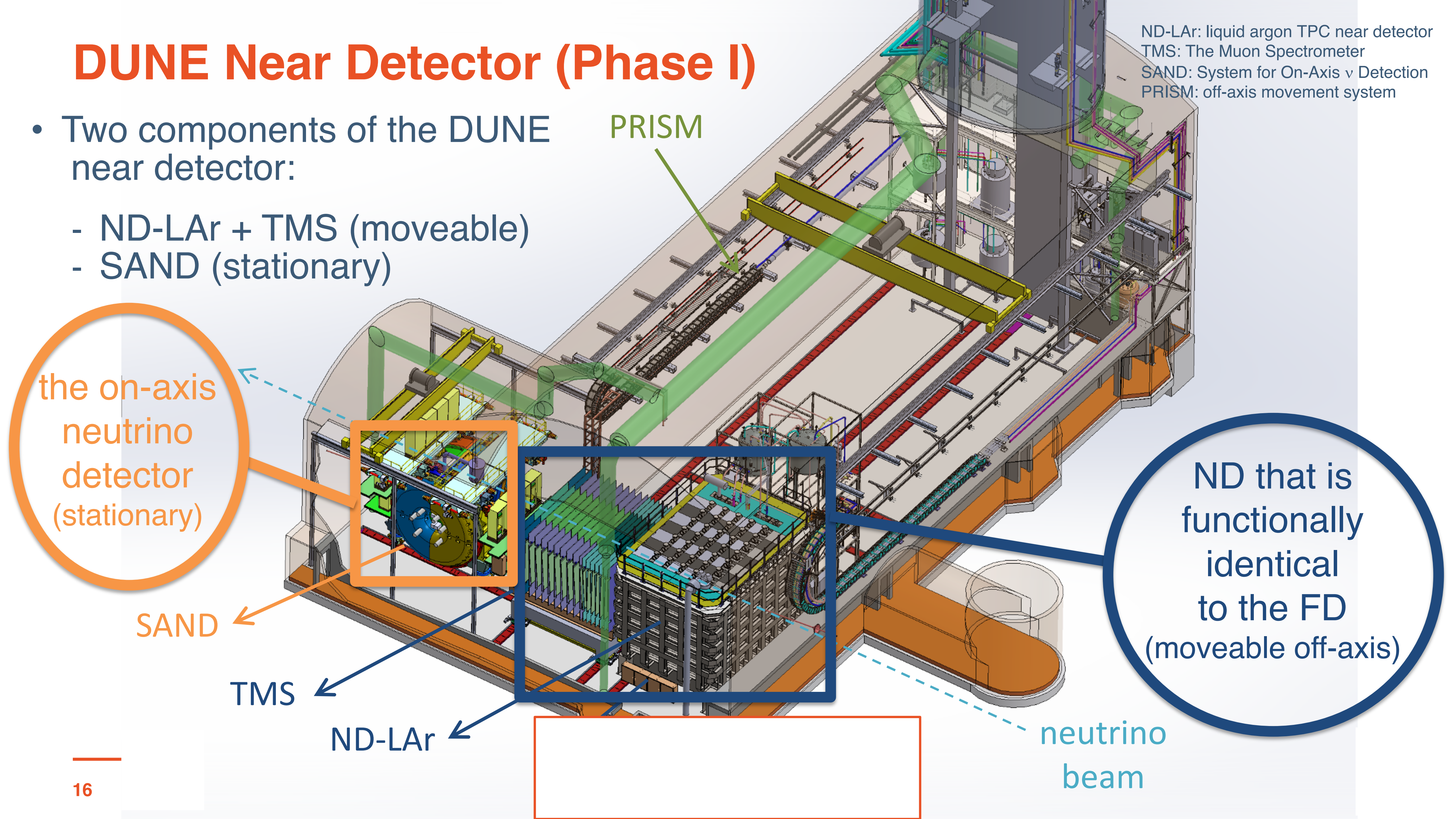
NOvA far detector

DUNE LAr TPC (ND-LAr) near detector →



DUNE Near Detector (Phase I)

- Two components of the DUNE near detector:
  - ND-LAr + TMS (moveable)
  - SAND (stationary)



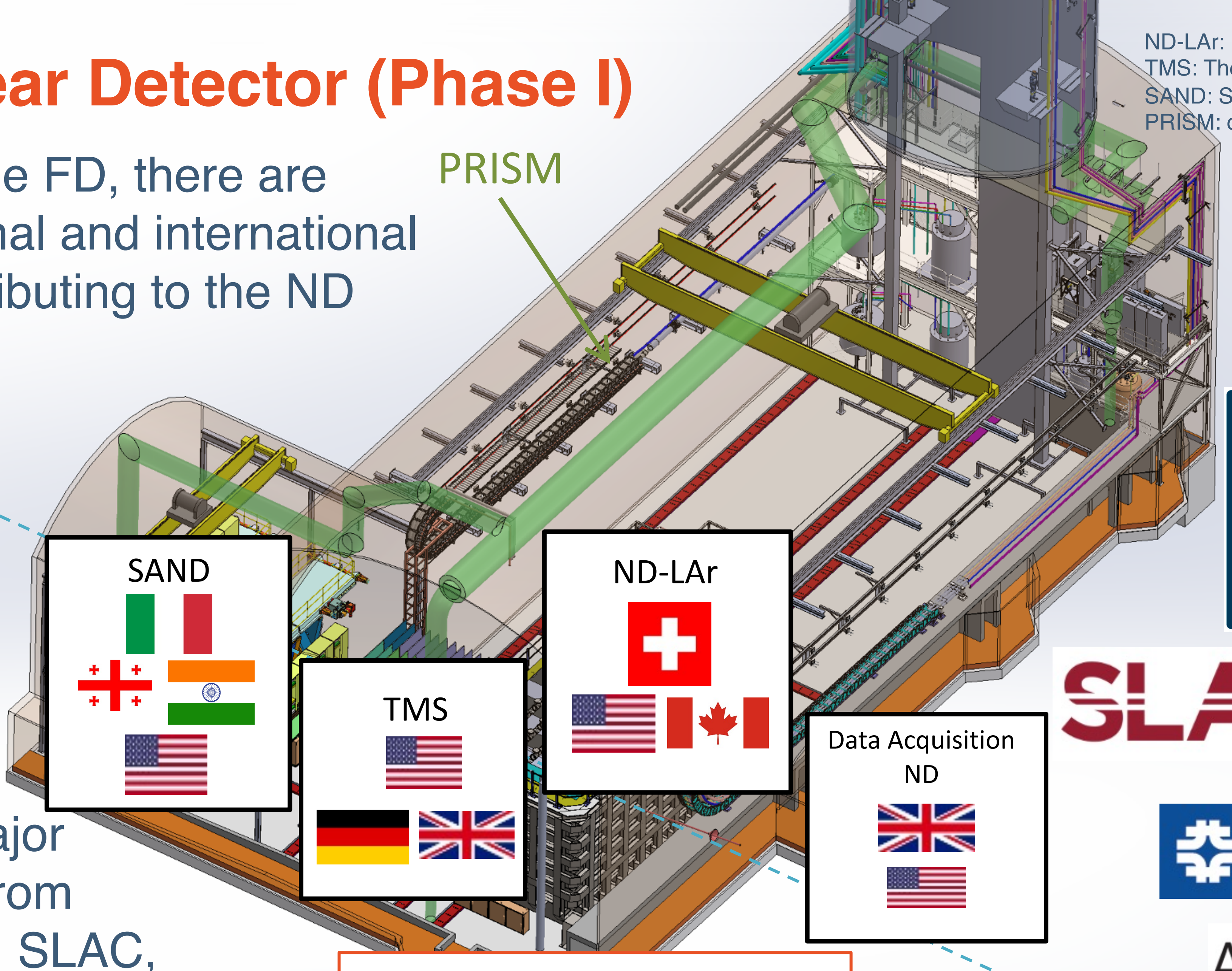
DUNE Near Detector (Phase I)

ND-LAr: liquid argon TPC near detector
TMS: The Muon Spectrometer
SAND: System for On-Axis ν Detection
PRISM: off-axis movement system

- Just as with the FD, there are multiple national and international partners contributing to the ND

- Our partners have been building prototypes & sending detector components

- In the U.S., major contributions from LBNL (pixels!), SLAC, ANL, FNAL, & Universities



BERKELEY LAB

SLAC NATIONAL ACCELERATOR LABORATORY

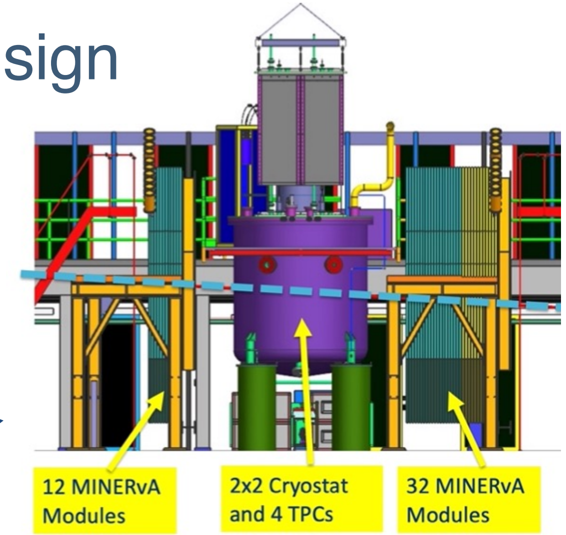
Fermilab

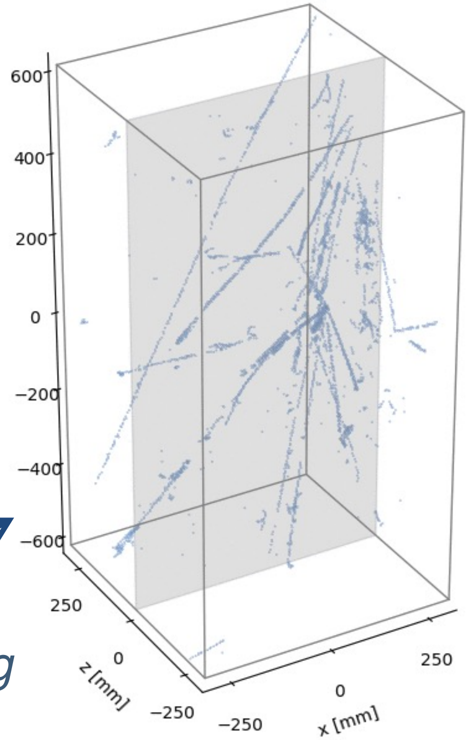
Argonne NATIONAL LABORATORY

DUNE Near Detector Status (Phase I)

- We are also building prototypes of the near detector
  - *2x2 Demonstrator in NuMI beam at Fermilab*
  - *Full Scale Demonstrator (FSD) of ND-LAr*
- Important to test pixelated, modular design
- Like with the protoDUNEs, we will be getting physics out of ND prototypes
- ND-LAr 2x2 Demonstrator is being installed in the NuMI beam
  - *this will be the first ν data from DUNE*
- Also, KLOE magnet is currently being disassembled in Frascati for shipment to Fermilab for SAND

National Institute for Nuclear Physics

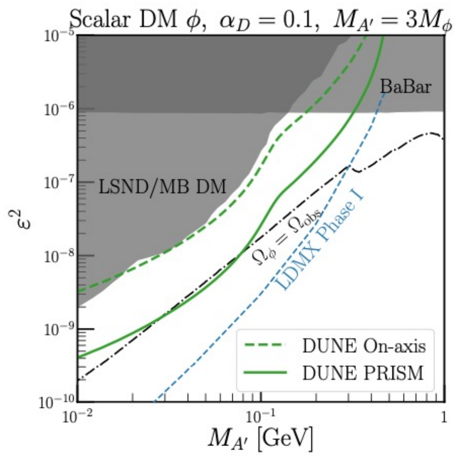




fully instrumented 20% scale ND-LAr module operating at U Bern, Switzerland

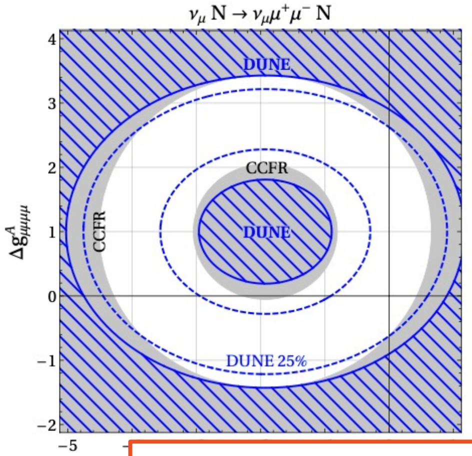
BSM Physics in Near Detector (Phase I)

- Primary role of the near detector is to enable ν oscillation physics in the far detector.
  - *this is what is driving the design of the near detector* *(Noemi Rocco's talk)*
- With the unprecedentedly large statistics, the DUNE near detector is also extremely sensitive to new physics. Lots of ideas from theorists! *(Pedro Machado's talk)*
  - *LAr TPCs open up new windows of discovery → exquisite imaging, ability to measure entire interaction, off-axis movement*
- Even more possible with Phase II near detector! *(Hiro Tanaka's talk)*

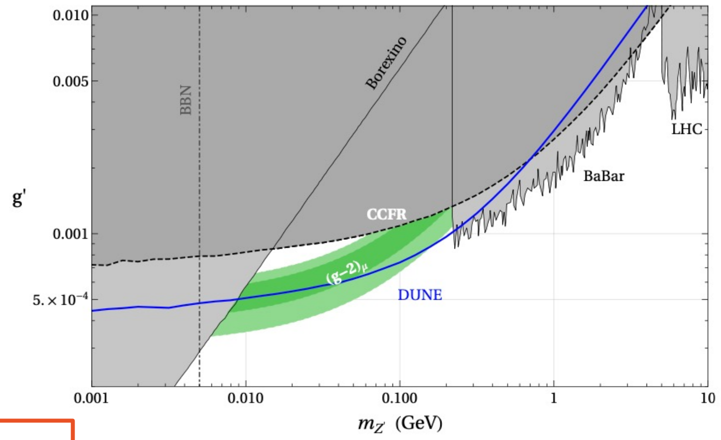


light dark matter

V. Romeri, K. Kelly, P. Machado, PRD 100, 095010 (2019)



trident search



extra Z' bosons

DUNE Collaboration, Eur. J. Phys. C81, 322 (2021)

Summary

- We took a bold step in uniquely choosing the LAr TPC technology for DUNE. We are well underway with preparations for both the Phase I far and near detectors.

  ☑ LAr TPCs deliver on their promise
    - *protoDUNEs have been a huge success*
    - *fire hose of physics results from MicroBooNE, ArgoNeuT (+ ICARUS, SBND soon!)*

  ☑ Large LAr TPCs are possible
    - *membrane cryostats have made large LAr TPCs & hence DUNE possible*
    - *argon purity is not an issue (LAPD, MicroBooNE, protoDUNEs, ICARUS)*
    - *combination of beam, baseline, LAr TPCs delivers better ν physics & BSM sensitivity*

  ☑ We are leveraging all of these successes in building towards Phase II
    - *Phase II far detectors (Mary Bishai's talk)*
    - *Phase II near detectors (Hiro Tanaka's talk)*

- Major breakthroughs have made this possible. These detectors will be giving us access to info we've never had access to before. We are truly entering a new era!

Acronyms

- APA = Anode Plane Assembly
- BSM = Beyond the Standard Model
- CRP = Charge Readout Plane
- DUNE = Deep Underground Neutrino Experiment
- FD = Far Detector
- HD = Horizonal Drift
- MO = Mass Ordering
- LBNF = Long-Baseline Neutrino Facilty
- ND = Near Detector
- ND-LAr = liquid-argon TPC near detector
- PRISM = Precision Reaction Independent Spectrum Measurement
- SAND = System for On-Axis Neutrino Detection
- SBN = Short-Baseline Neutrino
- SNEWS = SuperNova Early Warning System
- TMS = The Muon Spectrometer
- VD = Vertical Drift